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"Integrated Design Process" a Concept for Green Energy Engineering

Christian Koch[1], Henrik Buhl[2]
[1]Civil and Environmental Engineering, Chalmers University of Technology, Gothenburg, Sweden
[2]Department of Management Engineering, Technical University of Denmark, Kongens Lyngby, Denmark
Email: christian.koch@chalmers.se, hbuh@dtu.dk

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ABSTRACT

Consulting Engineers and Architects are currently experimenting with the concept of "Integrated Design Process" (IDP). This paper views Integrated Design Process as a process tool and a concept for management and organization of the green energy engineering process. Moreover such a concept is understood both as systematic knowledge and a symbolic device for enabling change. The paper briefly review international variants, and focus on two variants present in Denmark: an architect and engineering variant of IDP. The differences between the concepts include different roles for main actors, the use of information technology, the relation to lean, and forms of collaboration. The paper discusses two building projects focusing on teams of engineers and architects in the early conceptual phase. One develops a solution focused on energy saving technologies, the other on energy producing. It is argued that in this practical context, IDP is viewed as ambiguous and not well defined, and the architects and engineer work hard understanding and using the concepts even when directly involved. It is difficult to reach consensus on how to do it. The various players agree that an increased interdisciplinary interaction in the design team is necessary in order to comply with the increased complexity of green energy building design. IDP shows potential as a driver for green energy engineering and technologies, as traditional roles and responsibilities in the design process is changed, and sustainable solutions for green buildings can reach a higher standard and quality and are integrated earlier in the design process.

Keywords: Integrated Design Processes; Sustainable Building; Negotiated Concepts

1. Introduction

In Denmark it is estimated that 40% of the entire CO^2 emissions stems from the build environment, energy consumptions in buildings are one out of four main issues in the current climate transition towards a non fossil economy. The Danish Climate Commission work on the ambition of the European Union (EU), which states developed countries should collectively reduce their emissions of greenhouse gases by 60% to 80% by 2050 [1]. Designing clean buildings has become part of the fashion like phenomenon created around this societal and global agenda, call it LEED, BREEAM, Active houses, Passive houses, GreenBuilding, cleantech [2] or the like. Designing green and clean buildings involves meeting the elevated European directive's demands, a task that several studies shows is not simple for the professional service providers, the architects and the consulting engineers [3,4]. Part of the complication lies with the many competing concepts for climate change mitigation in building. Clients (and regulators) ask for more, or something else, than just following building regulations, and finding the right synthesis of design criteria and green energy technologies is challenging. A collection of green energy engineering technologies can be incorporated in the design of the buildings; solutions embrace possible extension using of panels, vertical windmill and thermal heating, ventilation and cooling systems etc. One of the central impacts of the need of designing green buildings is that energy consumption concerns and energy related requirements have to be engineered in an early conceptualization phase. Therefore in this paper the focus is on cases of conceptual design which are often be organized as "architects competitions", but with the introduction of integrated design (and energy calculations) also involves engineering consultants and for other reasons even contractors. What is in play in other words is a fundamental reorganization of previous linear and "over the wall" fragmented design processes [5]. Integrated Design Process (IDP) is here understood as a management concept. Concepts encompass recipes, process tolls and technology and varies globally, across countries and sectors [6]. This is also the case with IDP, and international variants are identified. In a Danish context it is assumed that local actors would translate and transform any such management concept rather than merely mimicking it. The preference in the theoretical framework is therefore given to Danish contributors, identifying three variants.

The aim of this paper is to analyze how Danish architectural and engineering companies interact with the concept of "integrated design processes" as part of their transition into delivering professional services of green buildings. The paper's empirical material encompass two building projects both aiming at going beyond the EU-requirements for energy consumption.

2. Method and Theory

The paper adopts a theoretical approach, which is multidisciplinary, with interpretive sociology as a central position, starting with identifying internationally present versions of IDP, as a background for characterizing three versions of integrated design present in Denmark. This part of the paper built on desk and a selective literature study, both identifying research based and more popular versions of the concept, following an approach like studies of management concepts [7]. The empirical part of the studies builds on case studies of four teams participating in a competition on two building projects with high profile energy demands. The choice of cases was done with point of the departure of collaboration with a consulting engineering company active in a network of architectural, engineering and construction firms heading in the direction of using integrated design and sustainable buildings. The two design competitions of building with energy requirements, each with two teams are covered by interviews of one engineer, and one architect from each team supplemented with two interviews with clients representatives. A desk study was used to complement on knowledge about the two competitions. The names of the two competitions are confidential; here they are called "Green Building" and "Low Energy Building".

IDP frameworks and cases/examples are introduced below which is the basis for the analysis. Theory about management concepts are used to analyze IDP as a concept, this implies that IDP is thought of as a loosely bundle set of ideas, visions, processual and content tools, exemplary cases and results. This stands in contrast to a belief that concepts used in enterprises would be founded on scientific systematic knowledge, and encompasses well defined and explicit tools [6]. When an enterprise or a group uses a concept, it would aim at directed change, realized through learning or even negotiation processes [7].

3. Integrated Design Processes (IDP)

Concepts of integrated design have been around for some time and are present both in academic literature and in companies' branding of competences etc. The focus on integrated design (without processes) is for example presented by [8]. [8] understands integrated design as what architects do, when they incorporate the energy, site, climatic, formal, construction, programmatic, regulatory, economic, and social aspects of a project as primary parameters for design. The concepts are clearly aimed at mitigating climate change, through creating sustainable buildings. One example given is the reduction of use of traditional power operated convectors in heating [8]. Reference [8] characterizes some recent changes in architecture as drivers for integrated design, as a new extended understanding of composition, a broadened understanding of the context and multivariate assemblage of factors and forces that compose buildings. This composition is seen as a confluence of two salient aspects; the energy milieu of every building site and the social construction of architecture [8]. The architect has a central role, albeit in another shape than previously, now the building project shifts from the twentieth century myth of the singular architect to thoroughly collaborative team structures. Social integration precedes technical integration. All technology is social before it is technical. The role of the architect shifts from individual master to strategic organizer of manifold, often disparate forms of knowledge and processes [8]. Where [8,9] places most of the competences and processes of integrative design among architects, [10] in their task force of the International Energy Agency (IEA) presents a comprehensive model for IDP, providing roles for a series of actors and a phase model encompassing iteration. Four phases are proposed basic predesign, concept design and design development [10]. The committed client and a core team of architects and engineers supplemented with further experts is the vital idea. It is claimed that energy design become integrated with architectural design rather than being an external add on. [11] claims that the weaknesses of the IEA model is too little focus on architectural quality and underestimation of cooperation challenges between engineers and architects. [12] is another similar comprehensive IDP concept with clear energy design focus.

The third example of an integrated design process concept is the International council for Research and Innovation in Construction's (CIB), publication on "Integrated Design and Delivery Solutions". Here integrated design is defined as "Integrated Design and Delivery Solutions use collaborative work processes and enhanced skills, with integrated data, information, and knowledge management to minimize structural and process inefficiencies and to enhance the value delivered during design, build, and operation, and across projects" [13]. The CIB concept combines collaboration, enhanced skills and IT-tools such as Building Information Models (BIM) and Knowledge Management with process elements from lean (design). Apart from the comprehensive process scope, there is also a clear focus on transforming industry; it is processes, technology and people of the build environment that need to change [13].

Summarizing, the international concepts of IDP there are different emphasis on which players are to "carry" the integrated design, what role technology and process methods should play and whether the concept is seen as a project approach or an industry approach.

4. Two Danish Variants of Integrated Design Processes

The interest now turns to two present variants of IDP in a Danish context, an architectural-oriented [13] and an engineering-oriented [14]. Both are embedded in more than one player in Denmark, both encompassing companies and universities.

The architectural oriented variant is developed at the Department of Architecture and Design at Aalborg University [13]. It is based on a holistic architectural approach and advocates for a close collaboration between architects and engineers, where buildings are is designed through an interdisciplinary approach. The approach is based on a common language between the architects and engineers. Hence, they must carry an interdisciplinary profile which incorporates skills from both professions. One of the fundamental tools in this approach is a comprehensive parametric analysis that allows the engineers to be more proactive in the design phase. The approach operates with four phases: Analysis, Sketching, Synthesis and Presentation. Joint decision making and corporation between all professions in all phases should be exercised. The architectural variant argues that engineers and architects should adapt their competences to each other and thereby create a common language from which they can design the building jointly. The engineering variant is developed at the Technical University of Denmark [14] is based on designing rooms before buildings in a "space of solutions" where each room is analyzed in accordance to predefined goals regarding energy performance and indoor environment by the engineers. The architect can subsequently design the building by combining the rooms in various ways based on the performance of the rooms [14,15]. It is possible to design various buildings that automatically fulfill the predefined performance goals. This approach decreases the trial and error design element, and claims to base the design on conscious decisions. The space of solutions is not intended to control the design but set the boundary condition. The approach is based on the assumption that indoor environment differ from room to room according to the specific orientation and internal load etc., hence, it is argued that it makes no sense to analyze indoor climate on building level in the design phase. The approach is less depended on joint decision making than the AAU method above, as the engineers and architects can work more individually. The approach focuses on the strengths of the different professions' skills and utilizes them in different phases in the design process. According to [14,15] integrated design involves four stages with particular roles (in parenthesis):

1) Establishing design goals (building owner and design facilitator);

2) Establishing design proposals for rooms and sections (building owner and design facilitator);

3) Generating proposals for rooms and sections (architects, experts and design facilitator);

4) Selection and optimization of final building design (building owner, design facilitator and experts).

The design facilitator role is share with the IEA concept discussed above. Also [14,15] advocate for the use of a specific IT-tool for handling the data on rooms in the building, "iDbuild" [15]. This is a simulation tool developed for generating design advice for a goal-oriented design process [15]. It relies on the power of building simulation tools in design. And with the intention to push performance evaluations into the early phase in the building design process to reduce costs.

[5] have followed and analyzed practical processes of Integrated Design and analyzed seven cases of use of IDP in an set of passive house projects. They find that most of the cases position themselves within the "extremes" of the engineering and architectural variants, whereas two adopt a more traditional design process. IDP causes different problems within the consortiums:

- Unclear boundaries compared to a traditional design process. Who does what and when?
- Different understanding of the same decision.
- The design teams focused so much on the technical aspects that they forgot the architectural qualities.
- Binding constraints that the architect was not able to design good architecture.
- The engineer felt too constrained because the architectural aspects were too fixed [5].

It follows that changes in the traditional design approach engender new ways to work as a team. Unclear roles and goals, ineffective communication, increased constraints and unfamiliarity with each others' processes prevailed in the cases—issues which emphasize the utilization of IDP. However, it should be noticed that these experiences are based on an entire project process and not the competition phase alone.

Summarizing the two Danish variants of IDP, have different emphasis on architectural and engineering competences and approaches to processes with different emphasis on project, organization, IT and lean principles.

The “profession variants” shows how the difficulties in creating common (mental) spaces for collaboration.

5. Designing Green Buildings with IDP

We now turn to the empirical material [16], two building projects with high energy ambitions is first described, followed by a description of the IDP process for two teams in each project. At each of the two projects, two competing project teams were interviewed addressing architects and consulting engineers, and also referring to clients and contractors representatives. Here the two teams’ responses are described to illustrate the process and expected results concerning green energy and sustainability issues. Project “Green Building” (GB) concerned a medium sized building (5000+ m^2). The client’s requirements to the building’s energy performance were tighter than what is required in the Danish building regulations (and EU regulation) and the client was focusing on facilitating IDP. The client arranged an invited project competition for five selected parties with duration of roughly three months. The client was represented by three partners: a contractor, the municipality, and a consultant. Out of the five prequalified teams, two project teams were chosen one of them was the winning team. The project teams consisted of a main architect, a main consulting engineer, and various sub consultants and specialists. The interviewees were the main architect and the main engineer from both teams and the client consultant. A client consultant was instrumental in developing the demands for sustainability of the building and the use of integrated design. For this consultant sustainability should be realized through a client drive and close collaborated of some form in the completion teams were viewed as crucial. The energy ambition was formulated as a concept where a synthesis of form, materials and technique, creates as building which on a yearly basis was energy neutral (web material). The ambition’s scope is energy consumption by heating and ventilations as defined in the building regulation, but also the individual consumption by lightning and use of household utilities. Upon finalizing the competition the winning project was characterized as “actively energy producing, energy neutral multi story dwelling, with comprehensive focus on health, perfect indoor climate and quality of life” (web material). The Client’s Consultant emphasis on the holistic design, and an integration in the process also implied looking for integration in the bids.

Project “Low Energy Building” (LEB) concerns a large scale building project (30.000+ m^2). The client invited selected companies to a Design/Build competition with duration of approximately three months. The client is represented by three partners which all are future users of the building. The project’s requirements concerning energy performance was also tighter than required in the regulations though there were no specific initiatives regarding facilitating IDP. Two of the prequalified teams were chosen. The project teams consisted of the Design/Build contractor, a main architect, a main consulting engineer, and various sub contractors, consultants, and specialists. The interviewees were the main architect and the main engineer from both teams and a contractor from one of the team. Furthermore, one of the clients was also interviewed. The client announced the competition, first as a prequalification round and then asking five selected teams to develop a proposal. Each project team could involve other consultants in order to secure the quality of the proposal, which the two studied teams did. When the winner was awarded, the proposal is contracted with the design/build contractor, which in turn hires sub contractors. The energy ambition of the building was to be able to obtain a class 1 level compliant with EPCB (2003) [17], which at the time of announcement equaled 50% of the present day Danish Building regulation. Secondly the occupants of the building should be actively involved in reducing the behavior oriented energy consumption. The LEB client asked for the use of Integrated Energy Design (EID), using a design process focused on climate appropriated design and user appropriated design and a planning of internal functions with emphasis on optimizing energy consumption. The process of team 1, LEB, as the client demanded the project teams to use integrated energy design, this was part of the ex ante requirements and the adoption beyond debate. This was interpreted as an advantage, as the Engineer said: “…it is an advantage that the client clearly states what he wants and can relate to that. It is easier to decode their requirements. ... And then the project teams do not need to interpret that much as they can see the level of ambition and what is expected” (Engineer team 1). The architect: “When we got the program we evaluated the winning parameters… And one can easily see that Integrated Energy Design, among other things, is of great importance. And we do adopt that, because it is an important part of this process and the contractor paid it a lot of attention, hence, and it was something we discussed every time” (Architect team 1). Whereas in contrast to EID, the architect saw IDP as more of an engineer’s concept, so where the engineer maps EID to IDP, the architect distinguished between them. The established project organisation scheduled a number of deadline and meetings. But according to the engineering consultant, things got more fluid, and there it was a strength that the architects firm managed to keep a partner (high level manager) onboard in the process, to enable joint decision making.

The process of designing energy was becoming a stronger synergy than normally: “All rooms were analyzed with regards to the internal load in relation to air change, so the architect could prioritize the locations of the room according to that. We put a lot of efforts in preparing the details before the architects came to the part" (Engineering Consultant). The architects think that the engineers were not able to contribute in the process, as they were too slow in decision making, because they need to calculate/compute the different solutions/ideas. So the problem is their tools, IT, and applications where it takes too long time to compute it and to try new things (Architect). A few tensions occurred relating to making contradictory demands meet. The product was a good experience, even if it could have been more interactive (Engineering Consultant). This team's energy design was evaluated by the competition committee to be excellent, as it arrived at the active house level, being able to produce energy. However the overall evaluation meant that the proposal did not win.

For team 2, LEB, the client demands for integrated energy design, the engineering consultant interpreted it as in direct prolongation of his company's own strategy of IDP: "So this way of thinking has gone all the way to the top management. In that connection a lot of workshops and internal training was held with our internal team members in order to implement this way of thinking" (Consulting Engineer).

The project organization encompasses a work groups and a steering group. The contractor participated in the steering group. Initially the winning parameters for the competition were discussed on a "mass meeting" where everyone in the team participated. A lot of meetings followed. Four broad workshops were arranged by each of the main partners. The energy design was made in a strongly collective and joint manner: "We made energy analysis of various initiatives and together we chose the best. It was not a single-handed assessment but a joint assessment about what would serve the project best. Not only energy but also in regards to architecture, price, constructability etc. We included it all" (Consulting Engineer). The process emerged as two parallel tracks: "The architect has a tendency to look at a building from the outside and in, which is a good exercise that has to happen early. At the same time the engineer is working on room level from inside and out where you examine what can be done with regards to energy at the specific location" (Engineer). The consulting engineers handled data on the rooms with an IT-tool enabling simulation of energy consumption with various room constellations: "Then you have something to contribute with before the first sketches are made. And it is so important that we start on that as it is the first sketches that set the direction for the further development of the building's form. These analyses must be put on the table from day one to find out what the facts are. The overall design we still leave to the architect. The idea is that you have a handful of rooms the architect can put together and make his design out of that" (Consulting Engineer).

In this manner it seems that team 2 was able to create synergy and synthesis even at an early stage. Team 2's design was evaluated as the winner by the competition committee. In term of energy design it arrived at the level 2 of the EU's "Energy Performance of Buildings Directive" (EBPD) [17].

6. Discussion of Danish Experiences with Integrated Design Processes

In the following we discuss four cases, four teams working with IDP: LEB team 1 and team 2; GB: team 3 and team 4. The interviewed team members have difficulties defining what integrated design "is" even after having participated in a process claimed to be governed by such a concept. The consulting engineers have gone further in taking up integrated design than the architects. One company (Engineering Consultant, LEB team 2) has implemented IDP internally. Another (Engineering Consultant, team 3 GB) have developed their version of integrated energy design, also as part of their business strategy, and claims identity between EID and IDP. The remaining two engineering companies hold competences in doing IDP, but are not strategically committed. It is clear that participant in all four teams struggle with the meaning and content of IDP, including what new roles and behavior to adopt. Central enabling factors for the process is the clients demand for it, previous collaboration, a "good feeling for each other", and an organic project organization enabling interaction and iterations, usually flat with little emphasis on the steering group level, and more emphasis on joint workshops with many participants. Some players go further in emphasizing that overly standardized methods would be inflexible in the variety of projects they engage in (Engineering Consultant, LEB team 1). It is contested among the participants whether IT tools for calculating energy features of the building are enabling or constraining the process. Some players see the tools as necessary to get the necessary valid calculations, whereas others, predominantly architects, sees the IT tools as constraining the interactive process, and would prefer sound judgment (Architects, LEB team1 and GB team 4). [15] similarly notes that engineering energy design IT-tools are evaluative, rather than prescriptive, which appears to constrain the engineering in early phase design. Also scheduling is seen as an ambiguous tool: the process has to be creative and interactive but the process is short (3 months) and intensive (GB team 3). Another contested element is how engineers manages their new role; both the architects and the engineers points at the need of a more open minded approach towards design opportunities, rather than problem solving. Most of the architects, interviewed evaluate the engineers as underperforming in this respect, although the interviewed engineers claimed to be focusing on these competences. This emphasizes the fundamental differences between the professions and their perception of each other.

The barriers for IDP currently seem to be the limited experience of most players, resource limitations, team recruitment and tools. The investigated projects suffered from significant resource limitations, hindering the fostering of the process innovation—a barrier which can be labeled the "Tyranny" of projects [18]. For some companies IDP is still to be adopted as a business strategy to support the development of IDP (presently two out of eight companies can be said to have such a strategy). By recruiting professionals with IDP experience and/or doing internal training the companies would enable the processes also beyond cases where building requirements and clients would require it [4]. The lack of tools and procedures to support the enforced interaction is remarkable. Neither [14,15] nor [13] have process models and tools directly provided for the process. One player refers to foreign books, but also rejects them (Engineering Consultant, GB team 4). CIB's ideas of using Building Information Models (BIM) and lean is not articulated [19]. As the two building projects studied were still under construction, it is not possible to evaluate the degree to which the climate objectives will be met, as one can expect the design to be challenged by cost cutting in the construction phase. At the presentation of both the designs, after the competitions, the energy features were highly flagged: At the LEB competition, team 1 actually provided the strongest proposal with a design were the house as such could be built with a negative energy consumption balance. This was characterized as excellent design by the evaluation committee. Team 2 wins the competition however, with a better balance between given design criteria; including (other) user requirements. It was subsequently announced that the building would comply to EBPD level 1 requirements, and with active involvement of future users in changing energy consuming behaviors. There was however nothing mentioned in the competition evaluation about future higher levels of EU-regulation, but merely a reference to contemporary Danish regulation, which at the time referred to EBPD [17]. At the GB competition the winning project (team 4) designed a building actively producing energy, with energy neutral dwellings, and simultaneously healthy, with good indoor climate and quality of life (for the future occupants). The client's consultant observed that some teams had not assured consistency within the material handed in, despite the calls intention of close collaboration (Client Consultant, GB). The cases studied represent clients going beyond present building regulation, and consulting enterprises with the competences needed, in contrast to results by [4] showing that most consulting engineering companies studied in Norway prefer to stick to existing building regulation (which is probably parallel to Danish consultants). Going beyond the building regulation implies that the design teams embark on less well defined ground in setting the environmental level in the design and balancing it with other criteria such as cost. At LEB the initial design ambition was to design the building without photovoltaic or thermal panels as such solutions were perceived as too easy by the engineers. The design building complies with EBPD 2015 or energy class 1 without using panels or energy producing technologies. This is obtained by a thorough design of the building envelope using special windows and a range of other technologies such as regenerative elevators and solar preheating of ventilation air. The proposed design solution includes an possible extension using panels, a vertical windmill and thermal heating, green energy producing technologies that improves the energy performance further. Moreover it is intended to continue to optimize the energy balance of the building through control systems, ventilation and cooling systems. In the LEB case, synthesized design appeared to master this balance better than design focusing only on energy. The building envelope of GB is characterised by higher isolation ability and higher airtightness. Photovoltaic panels and combined photovoltaic-thermal is used as solution to the limited roof space compared to the size of the building. However when present building regulation is not used, then other higher, but still normative levels are referred to, *i.e.* the "active house" criteria, meaning that the house produce energy rather than consuming it [20]. Notably at this early stage of design there is no attempt to refer to broader standards and norms for sustainability such as Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB, German Sustainable Building Council [21]) or Leadership in Energy and Environmental Design (LEED [22]). These norms would extend the focus on the building and the product, which was adopted here.

7. Conclusion

A range of green energy technologies is incorporated in the design of the two building projects analysed in this article. The projects, as well as Danish and international variants, shows that ambiguous concepts of IDP exist, and the architects and engineers work hard to utilize the concepts, even when directly involved. Difficult negotiations amongst the participants have to be carried out to assure consensus. The participating engineers, architects, clients and clients counsellers agree that an increased interdisciplinary interaction in the design team is necessary in order to tackle the increased complexity of sustainable building design involving green energy technology. This tendency changes the traditional roles and responsibilities in the design process which leads to misalignments of expectations in the design team. The projects studied represent clients willing to go beyond present public building regulation. This implies that the design teams embark on less well defined ground in setting the environmental level in the design and balancing it with other criteria such as cost. Even then the tendency of the design teams is to refer to other standards, which are slightly tighter than the present regulation, impairing a more creative design, which is actually counter to the ideas of integrated design. IDP still seems to be a promising concept for Green Energy Engineering as these issues hopefully would be overcome in the future.

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